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Effects of planting spacing and site quality on 25-year growth and mortality relationships of Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*)

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ABSTRACT

Growth and mortality of coast Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) were studied for 25 years after planting seedlings at 1–6-m spacings on a site of moderate quality in the western Cascade Mountains of Washington. Responses were compared to those from two other studies representing high and low site qualities. Third-year height did not differ among spacings ($P = 0.80$), providing no evidence that close spacing stimulated early growth. Piecewise regression identified the onset of competition-induced mortality when stand density index (SDI [Reineke, L.H. 1933. Perfecting a stand density index for even-aged forests. Journal of Agricultural Research 46, 627–638]) exceeded 52% (S.E. = 4.6) of the species' maximum or when average crown ratio (CR) declined below 52% (S.E. = 0.9). For a range of SDI values, CR averaged 2–7% points greater at the high-quality site than at the moderate-quality site. In a regression analysis of combined data from the moderate- and high-quality sites, relative values of average stem diameter and stand volume (% of maximum values observed per site) 23–25 years after planting increased and decreased with planting spacing, respectively ($R^2 = 0.97$ and 0.91, respectively). Intersection of these relationships at 3-m spacing indicated a point of equivalent relative development of tree size and stand yield. For a range of site qualities, stands planted at 3-m spacing: (1) maintained tree vigor (CR ≥ 50%) and stability (average height:dbh ratio <90), (2) experienced little or no competition-induced mortality through age 25 years, and (3) allocated 25-year growth equitably to development of tree size and stand yield, thereby providing a desirable starting point for subsequent management.

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1. Introduction

Spacing is a critical feature to consider when establishing forest plantations because it determines the timing and intensity of resource competition among individual trees. Given the limited pool of resources available to support tree growth on a forest site, competition among individual trees intensifies as they grow in size and their resource requirements increase. Trees become dominant within a stand when their initial size, genetic characteristics, or resource availability enable them to grow faster, suppress their neighbors, and occupy additional growing space. Spacing affects the timing, and therefore tree size, at which these competitive interactions occur (Long et al., 2004). In this way, spacing directly influences stand dynamics associated with differentiation in tree size and onset of competition-induced mortality.

Typical planting spacings for coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) are based on a variety of criteria, including forecasts of tree survival, growth, and stability (Talbert and Marshall, 2005). These criteria often are viewed as components of stand vigor, and one goal of selecting the proper spacing is to enable crop trees to maintain their vigor until a subsequent thinning or other treatment. Maintaining crown ratio (live crown length:tree height ratio) at 40% or greater is considered desirable for sustaining vigorous growth (Smith, 1986, p. 83), although few studies have experimentally manipulated this variable or related it to stand density to identify critical values for stand management (Young and Kramer, 1952; Long, 1985; Dean and Baldwin, 1996a). Likewise, maintaining the ratio of height:stem diameter (i.e., slenderness ratio) below 80–100 is considered desirable for reducing susceptibility to wind-throw and stem breakage, especially when stand height exceeds 25 m (Cremer et al., 1982; Lohmander and Helles, 1987; Wilson and Oliver, 2000). As initial spacing decreases, risk of declining vigor from accelerated crown recession (i.e., mortality of lower branches) or loss of stability from development of a high slenderness ratio occurs earlier in stand development. Declining vigor from intense competition increases the probability that an individual tree will die. The onset of competition-induced mortality in stands of coast Douglas-fir has been estimated to occur when stand density index (SDI; Reineke, 1933) exceeds a

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